under opacities 1 and 2 is small. In view, however, of the consistently lower values obtained for E_+/E_- for opacity 2, there can be little doubt that the difference is real. For opacities greater than 2, the increase in the negative charge and the reduction in E_+/E_- seems fairly established, in spite of the undesirably low number of the observations.

The effect of mist and fog is to increase the free negative charge in the air near the ground (which has its usual negative surface charge enhanced by fog), but so greatly to reduce the mobility of the ions that in spite of the increased potential gradient there is a substantial reduction of the air-earth current.

Mean values for E_+, E_-, and E_+/E_-, based on observations made at Kew Observatory during 1911, 1912, and 1914, and a discussion of the apparatus and methods will be found in papers by Messrs. Gordon Dobson* and E. H. Nichols.†

On the Nature of Sun-Spots.

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The researches described in the present paper were undertaken in connection with a more general investigation of the sun, considered as a typical star. The gradual development of the work dates from 1891, when three attacks, along converging lines, were begun by the writer at the Kenwood Observatory. One of these involved a study of the spectra of sun-spots, requiring the development of instruments and methods adequate to record photographically the minute peculiarities of their widened lines. The second was a photographic investigation of the solar atmosphere, rendered possible by the initiation and gradual improvement of the spectroheliograph. A series of laboratory experiments was also undertaken for the purpose of interpreting the phenomena detected in both of these series of researches.

The forms of the bright calcium flocculi, first recorded with the spectroheliograph in 1892, afforded no definite evidence of currents in the sun's

* 'Meteorological Office Geophysical Memoirs,' No. 7, vol. 1, p. 155, especially pp. 162 *et seq.*

† 'Terrestrial Magnetism and Atmospheric Electricity,' vol. 21, p. 87 (1916).

atmosphere. At the Yerkes Observatory, with more powerful instrumental means, the forms of dark flocculi, photographed in 1903 with the blue and violet hydrogen lines, gave some indications of fields of force centering in sun-spots. These were not fully recognised, however, until 1908, when, as the result of further improvements of technique, sharply-defined vortices, centering in sun-spots, and corresponding to a higher level in the solar atmosphere, were photographed at the Mount Wilson Observatory. These photographs suggested the hypothesis that a sun-spot is an electric vortex, in which the whirling ions may give rise to a magnetic field. In this case the widened lines in the spot spectrum should exhibit the characteristic features of the Zeeman effect.

Meanwhile a method of photographing the sun-spot spectrum, on a scale sufficient to permit this question to be tested, had resulted from the design and construction on Mount Wilson of the 60-foot "tower telescope," a fixed vertical telescope forming a large image of the sun on the slit of a spectroscope of 30 feet focal length, mounted in a subterranean chamber at the base of the tower. The characteristic polarisation phenomena of lines split by a magnetic field were at once detected, thus giving strong evidence that sun-spots are electric vortices.

The magnetic polarities and field-strengths of all sun-spots are now recorded daily on Mount Wilson with a 150-foot tower telescope, affording data for the determination of the law of solar storms. A large percentage of all sun-spots are double, the two members being of opposite magnetic polarity. The preceding members of such groups in the northern and southern hemispheres are of opposite polarity, indicating opposite directions of whirl, as in terrestrial cyclones. Since the sun-spot minimum in 1912 the polarities of preceding spots in a given hemisphere have been found to be opposite in sign to preceding spots observed in the same hemisphere before the minimum. Thus the polarities seem to be intimately connected with the cause of the sun-spot cycle.

Studies of the Zeeman effect in sun-spots give the direction of the lines of force of the magnetic field, and hence of the axis of the electric vortex, which is nearly normal to the sun's surface. Further light on the nature of this vortex is afforded by the relationship between field-strength and the spot's diameter, the level of the observed vapours in the solar atmosphere, and their distance from the spot's centre, and by other phenomena associated with unipolar and bipolar spots.

The frequent occurrence of spots in pairs, of opposite polarity, suggested the hypothesis that such spots might represent the opposite extremities of a semi-circular vortex ring, extending beneath the photosphere, with a plane

normal to the sun's surface. A simple experiment shows how a columnar vortex, formed in water, may be transformed into a semi-circular vortex ring. It is not supposed, however, that this hypothesis, though a useful guide to research, can often apply literally to sun-spots, especially in the case of complex spot-groups.

Another simple experiment may aid in explaining the hydrogen vortices in the solar atmosphere above sun-spots. Two paddles are rotated in opposite directions in water, just below the surface. The circulation upward and spirally outward along the surface probably resembles that in sun-spot vortices. Secondary vortices are thus set up by friction in a quiet smoky atmosphere above the water. In these smoke vortices the circulation is spirally inward, downward, and outward at the water surface, apparently as in the case of solar hydrogen vortices, which they closely resemble in structure.

The rival claims of the electromagnetic hypothesis, which explains the vortex structure in the solar atmosphere on the supposition that the hydrogen flocculi render visible the trajectories of electrically charged particles moving under the influence of magnetic fields in sun-spots, may be tested by determining the relationship between direction of whirl and spot polarity.

Some of the phenomena connected with the general magnetic field of the sun, detected as an outgrowth of this investigation, throw further light on the nature of sun-spots. A search for direct evidence of the existence of electric fields in the sun has hitherto yielded negative results.